

4th Satellite Soil Moisture Validation and Application Workshop

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The purpose of the Satellite Soil Moisture Validation and Application Workshop series is to discuss and reconcile methodological advances in the development, validation and application of global satellite soil moisture data. The workshops bring together satellite teams with validation experts and users to focus on the derivation, validation and exploration of soil moisture data from passive and active microwave satellite missions. These include but are not limited to the National Aeronautics and Space Administration (NASA) Soil Moisture Active Passive (SMAP) mission, the European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) mission, the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) Advanced Scatterometer (ASCAT) on board the series of MetOp satellites, the Japan Aerospace Exploration Agency (JAXA) Advanced Microwave Scanning Radiometer 2 (AMSR2) and the Synthetic Aperture Radar (SAR) on board the ESA Sentinel-1 satellites.

The fourth workshop in the series was jointly organized by the Vienna University of Technology (TU Wien), the U.S. Department of Agriculture (USDA), Vandersat, George Mason University and the Earth Observation Data Centre for Water Resources Monitoring (EODC). Co-sponsoring and support came from ESA, EUMETSAT, the Austrian Research Promotion Agency (FFG), the World Meteorological Organization (WMO), GEWEX, the Global Climate Observing System (GCOS), the Committee on Earth Observation Satellites (CEOS) and the Multidisciplinary Digital Publishing Institute (MDPI). More than 100 scientists from 22 countries participated, representing a large cross section of the soil moisture community. The workshop opened with an in memoriam tribute to Alexander Löw from the Ludwig Maximilian University in Munich, Germany, who had always been an active supporter of this workshop series. He led several international community projects such as the review of “Validation practices for satellite-based Earth observation data across communities,” which was published only recently in the *Reviews of Geophysics*.

Many presentations at the workshop focused on the SMAP satellite that was launched less than three years ago on 31 Jan-

uary 2015. These presentations corroborated the very encouraging initial SMAP results presented at the last soil moisture workshop held in September 2016 in New York. This year's results confirmed that the SMAP brightness measurements are within specifications and the soil moisture retrievals meet the mission requirement of an unbiased root mean square error of 0.04 m³m³. Comparison of SMAP data with retrievals from other satellite (e.g., SMOS, ASCAT, AMSR2) and in situ measurements from around the world furthermore confirmed that the performance of the different soil moisture data products is variable in space and time, and that the best results can be achieved by combining observations from the different satellites and by assimilating the satellite observations into land surface modeling systems (see figure on next page).

In efforts to derive higher resolution soil moisture data products, Sentinel-1 SAR data have received the most attention. Sentinel-1 data are very attractive but are not easy to deal with due to the large data volume and the increased complexity of the processes when moving from the 20-50 km scale to 1 km or even to field scale. As a result, most studies have used Sentinel-1 for the downscaling of the coarser-resolution instruments (e.g., SMAP, SMOS, ASCAT, AMSR), rather than attempting a direct retrieval.

Satellite soil moisture data have been taken up by a wide variety of users (e.g., meteorologists, hydrologists, agricultural users); several real-world applications are benefiting from using and integrating such observations. At the workshop, it was shown that the assimilation of satellite soil moisture observations improves flood prediction, even in medium-sized basins (less than 500 km²). Further evidence of the added value of satellite soil moisture data includes, among other benefits, the improvement of energy flux estimation through land-surface modeling, the advancement in the estimation of satellite precipitation and, recently, the detection and quantification of irrigation. However, it was observed at the workshop that additional effort is required to achieve a greater involvement of the user community. Specifically, better communication about limitations of the data is needed to avoid wrong usage (e.g., under frozen soils or in densely vegetated areas) and to inform them of the different satellite soil moisture products that are currently freely available. Capacity building is fundamental to globalizing societal applications of satellite soil moisture data sets and building consensus on key questions and recommendations.

The workshop concluded with a discussion in which the following two questions were addressed: (1) Is there a need for updating the GCOS accuracy requirements? and (2) What are the recommendations for future satellite soil moisture missions?

GCOS Accuracy Requirements for Soil Moisture

Soil moisture was endorsed by GCOS as an essential climate variable (ECV) in 2010. As a result, GCOS regularly assesses the observation capabilities for soil moisture (both the satellite and in situ components), identifies gaps in observational capabilities and formulates/updates observation requirements. Workshop participants were asked whether the observation requirements for surface soil moisture observations as presently

formulated in Annex 1 of the GCOS 2016 Implementation Plan (temporal sampling of 1 day, spatial resolution 1–25 km, accuracy of $0.04 \text{ m}^3/\text{m}^3$ and stability of $0.01 \text{ m}^3/\text{m}^3/\text{year}$) are still appropriate. The consensus was that these requirements are still adequate. However, workshop participants expressed the need for a clearer definition of these requirements. Furthermore, the workshop participants emphasized the need to consider variables that are closely related to soil moisture, such as vegetation optical depth, freeze/thaw, surface inundation and root-zone soil moisture, which is in line with the GCOS 2016 Implementation Plan.

Recommendation for an L-Band Follow-on Mission

As an introduction to this discussion topic, the initial concept for the Copernicus Space Component Evolution was presented. The European Commission identified monitoring greenhouse gases, polar regions and agriculture as the highest priorities based on an interim conclusion of user requirement analyses. These were followed by soil moisture together with other parameters, such as biodiversity and mining. The next generation of Sentinel-1 satellites could potentially include an L-band SAR system and low frequency radiometers (e.g., for L- and C-band).

The workshop participants welcomed data continuity for the C-band SAR on board Sentinel-1, as it has proven its value for delivering information at high spatial resolution. Although the absolute accuracy of Sentinel-1 soil moisture retrievals is at present still low, the measurements have been used to down-scale the more accurate larger-scale soil moisture estimates from active and passive systems (i.e., ASCAT, AMSR2, SMOS and SMAP). While continuity for ASCAT and AMSR is foreseen, the participants were highly concerned regarding the long-term continuity of passive microwave L-band observations.

Therefore, it was strongly recommended to start activities defining a future L-band observation system based on the lessons learned from SMOS and SMAP. In addition, efforts will be

made to keep L-band as a protected band for scientific applications and to detect out-of-band emissions so that regulatory measures can be taken.

Across missions and applications, the workshop participants agreed on the high value of representative and verified in situ measurements as a means for independent validation of the different satellite data products; the International Soil Moisture Network (ISMN) will be continued as the primary global database for harmonized and quality checked observations.

CCI Soil Moisture User Workshop

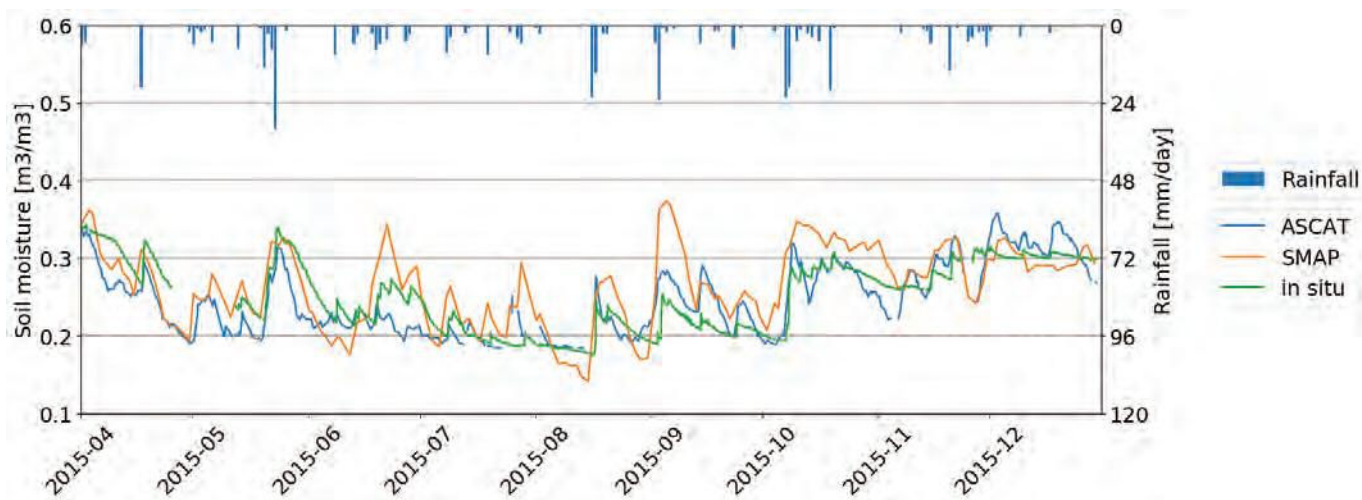
The soil moisture workshop was preceded by a one-day soil moisture user workshop organized within the framework of the ESA Climate Change Initiative (CCI) programme. The goal of this workshop was to bring together producers and users of the ESA CCI multi-sensor soil moisture product. Almost 80 scientists attended the workshop. One of the key messages uncovered by the discussions was that data consistency over time is one of the major requirements for a long-term data record like ESA CCI soil moisture. The user feedback provided important suggestions for potential future improvements (e.g., the use of an L-band climatology as a reference to which all other sensors shall be scaled) and the production of a root zone soil moisture product.

Next Workshop

The 5th Satellite Soil Moisture Validation and Application Workshop is scheduled for 24–25 October 2018 at George Mason University, Fairfax, Virginia USA. The plan is to focus the workshop on soil moisture applications.

Special Issue

Selected papers that expand on the workshop presentations will appear in the journal *Remote Sensing*, collected in a special issue entitled “Retrieval, Validation and Application of Satellite Soil Moisture Data.” (http://www.mdpi.com/journal/remotesensing/special_issues/soilmoisture).



Comparison of SMAP L3 and ASCAT H109 soil moisture retrievals to in situ measurements from the Hydrological Open Air Laboratory (HOAL) site in Petzenkirchen, Austria.